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How To Control and Reap the Benefits of HID Lamps

Electronic HID (high intensity discharge lamp) ballasts: how they work, how to control them, and develop an electronic ballast solution for outdoor lighting applications.

H brightness metal halide lamps typically have an efficacy of greater than 100 lumens/watt and have a lifetime of 20,000 hours. HID lamps produce light using a technique similar to that used in fluorescent lamps where mercury atoms are excited by an electrical current resulting in the production of ultraviolet (UV) light. The UV light is then converted into visible light through a phosphor coating on the inside of the tube. In the case of HID lamps, they operate at a high-temperature and high-pressure, the arc length is very short, and visible light is produced directly without the need for a phosphor.

Metal halide lamps (*Figure 1*) comprise an arc tube surrounded by an outer bulb envelope. The arc tube is made of quartz or ceramic glass, has tungsten electrodes located at each end, and contains a mixture of argon, mercury and metal halide salts. Metal halide is added to the lamp to increase lumens and improve the light color.

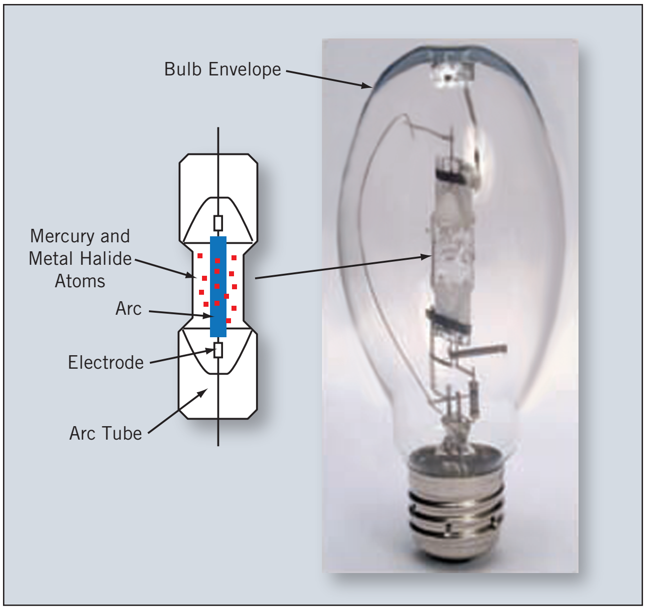


Fig. 1. HID lamps comrpise an arc tube surrounded by an outer bulb envelope.

The lamp is started by applying a high voltage pulse across the tube to ionize the argon gas. Once the gas is fully ionized, a sustained arc extends from one electrode to another and current (supplied by a ballast) flows across the tube. As the pressure and temperature inside the tube increase, the materials within the arc tube vaporize and light is emitted in the form of visible light and UV radiation. The outer bulb envelope provides a stable thermal environment for the arc tube, prevents oxidation of the arc tube, and reduces the amount of UV radiation emitted by the lamp.

HID LAMP CHARACTERISTICS

HID lamps require a high voltage for ignition (3 to 4KV typical, >20KV if the lamp is hot), current limitation during warm-up, and a constant power during running. It is important to have a tight regulation of lamp power to minimize lamp-to-lamp color and brightness variations. Also, HID lamps are driven with a low-frequency AC voltage (<200Hz typical) to avoid mercury migration and to prevent damage of the lamp due to acoustic resonance. A typical metal halide 250W HID lamp has the following characteristics:

- Nominal Wattage (W): 250

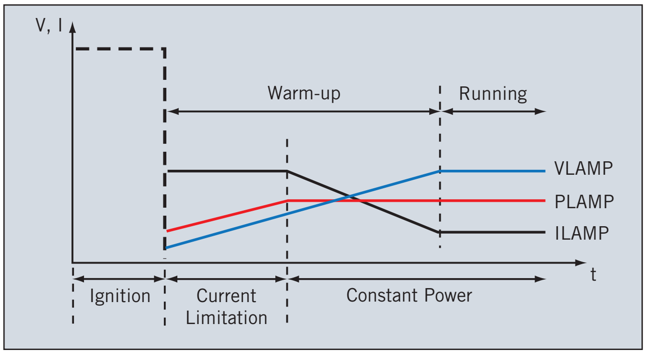
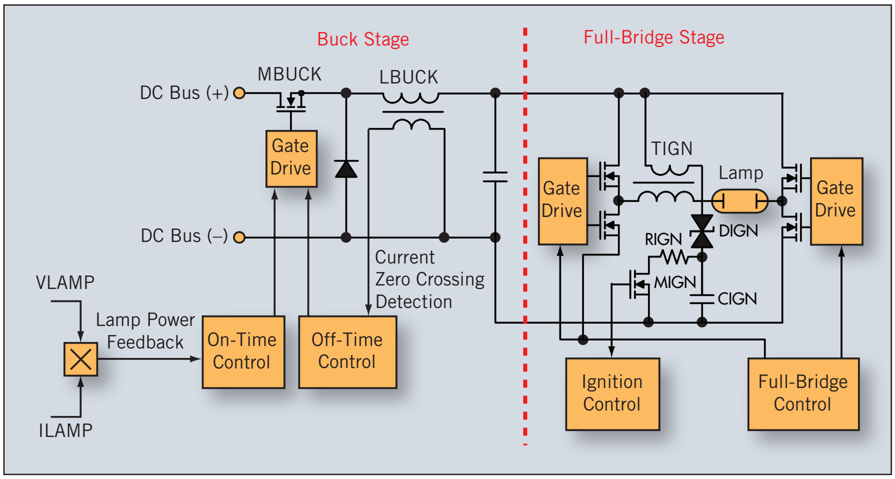


Fig. 2. Typical start-up profile for HID lamp ignition, warm-up and running modes.

Fig. 3 HID lamp ballast circuit employs a buck stage to control the lamp current, followed by a full-bridge output stage for ac lamp operation.



- Nominal Voltage (Vrms): 100
- Nominal Current (Arms): 2.5
- Warm-up Time (min): 2.0
- Ignition Voltage (Vpk): 4000

Figure 2 shows the typical start-up profile for HID lamps. Before ignition, the lamp is open circuit. After the lamp ignites, the lamp voltage drops quickly from the open-circuit voltage to a very low value (20V typical) due to the low resistance of the lamp. This causes the lamp current to increase to a very high value and should therefore be limited to a safe maximum level. As the lamp warms up, the current decreases as the voltage and power increase. Eventually, the lamp voltage reaches its nominal value (100V typical) and the power is regulated to the correct level.

To satisfy the lamp requirements and different oper-

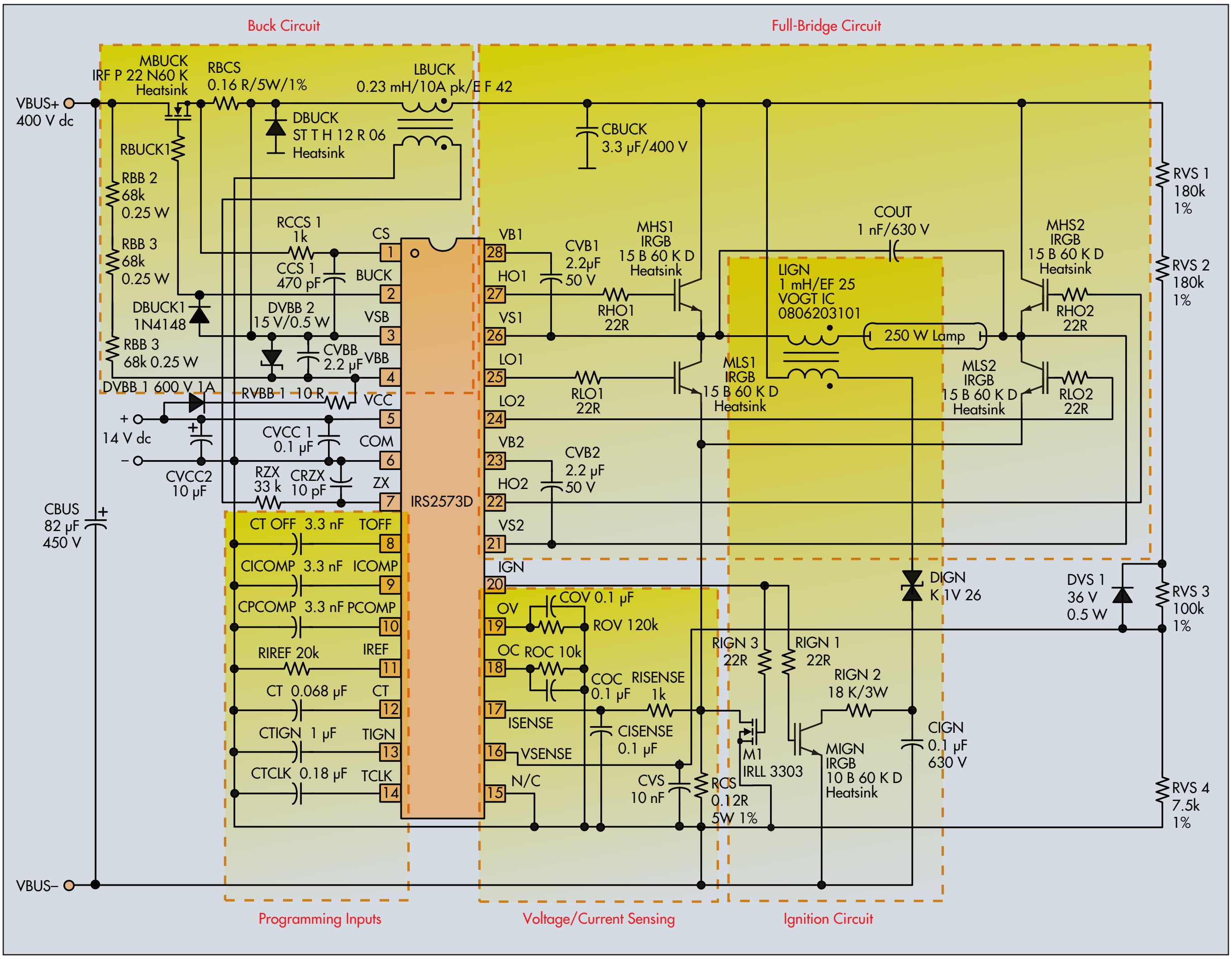
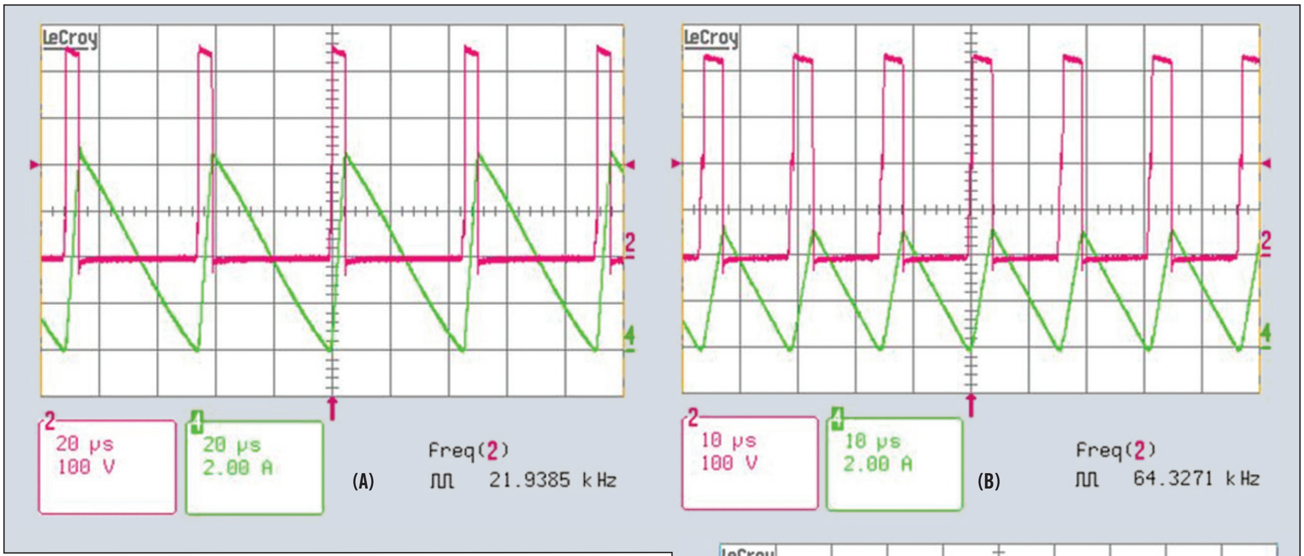


Fig. 4 250W HID ballast circuit uses a complete buck and full-bridge control circuit designed around the IRS2573D HID Control IC.



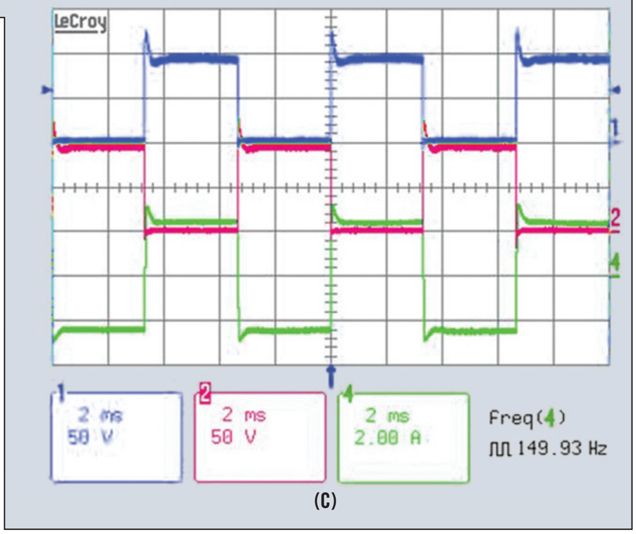


Figure 5 HID ballast waveforms

A) During lamp warm-up: buck switching node voltage (upper trace); buck current (lower trace).

B) During normal lamp running: buck switching node voltage (upper trace; buck current (lower trace).

C) During normal lamp running: half-bridge output voltage (upper and middle traces); ac lamp current (lower trace).

ating modes, an electronic ballast circuit is needed that ignites the lamp, controls lamp power, and produces an AC lamp voltage.

HID BALLASTS

The standard circuit for controlling HID lamps includes (*Figure 3*) a buck stage for controlling the lamp current, followed by a full-bridge output stage for ac operation of the lamp. The output stage also includes an ignition circuit for striking the lamp. A control circuit or IC is necessary to control the buck and full-bridge stages and properly managing the different lamp modes. The buck circuit is fed by a constant dc bus voltage (400Vdc, typical) that can be supplied by a commonly used active power factor correction circuit.

The buck stage is the main control circuit of the ballast and is used to control the lamp current and power. The buck stage steps the dc bus voltage down to the lower lamp voltage at the full-bridge stage. The lamp voltage and current are measured and multiplied together to produce a lamp power measurement. The lamp power measurement is then fed back to control the on-time of th buck switch (MBUCK). The buck off-time each switching e cycle is determined by the zero-crossing of the buck inductor current and is sensed using a secondary winding from the buck inductor (LBUCK).

The full-bridge stage is necessary to produce an ac lamp current and voltage during running. The full-bridge typically operates at 200Hz with a 50% duty-cycle. The full-bridge also contains a pulse transformer circuit for producing 4KV pulses across the lamp necessary for ignition. The ignition circuit includes a diac circuit to produce the required ignition pulses. The ignition circuit is activated by turning on MIGN, causing the lower leg of the diac, DIGN, to discharge with a time constant determined by RIGN and CIGN. When the voltage across the diac reaches the diac threshold, the diac then diac breaks down and a voltage pulse is produced across the primary winding of the ignition transformer, TIGN. This produces 4KV pulses across the secondary winding of TIGN and across the lamp for ignition.

The complete buck and full-bridge control circuit schematic is shown in *Figure 4*. The circuit is designed around the IRS2573D HID Control IC from International Rectifier. The IRS2573D includes control for the buck stage, the full-bridge, lamp current and voltage sensing, and feedback loops for controlling lamp current and lamp power. The IC includes an integrated 600V high-side

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driver for the buck gate drive (BUCK pin) with cycle-by-cycle over-current protection (CS pin). The on-time of the buck switch is controlled by the lamp power control loop (PCOMP pin) or lamp current limitation loop (ICOMP pin). The off-time of the buck switch is controlled by the inductor current zero-crossing detection input (ZX pin) during critical-conduction mode, or by the off-time timing input (TOFF pin) for continuous-conduction mode. The IC also includes a fully-integrated 600V high- and low-side full-bridge driver. The operating frequency of the full-bridge is controlled with an external timing pin (CT pin). The IC provides lamp power control by sensing the lamp voltage and current (VSENSE and ISENSE pins) and then multiplying them together internally to generate the lamp power measurement. The ignition control is performed using an ignition timing output (IGN pin) that drives an external ignition MOSFET (MIGN) on and off to enable the ignition circuit of the lamp (DIGN, CIGN, TIGN). The ignition timer is programmed externally (TIGN pin) to set the ignition circuit on and off times. Finally, the IC includes a programmable fault timer (TCLK pin) for programming the allowable fault duration times before shutting the IC off safely when various fault conditions occur. Such fault conditions include failure of the lamp to ignite, failure of the lamp to warm-up, lamp end-of-life, arc instabilities, and open/short circuit of the output.

WAVEFORMS

Figure 5 illustrates the experimental results. Figure 5A shows the buck switching node voltage (upper trace) and buck current (lower trace) during lamp warm-up. Figure 5B shows the buck switching node voltage (upper trace) and buck current during steady-state running conditions. The buck is working in critical-conduction mode during steady state running conditions and the on-time is controlled by the constant power feedback loop. Figure 5C shows each half-bridge output voltage (upper and middle traces) and ac lamp current (lower trace) during normal lamp running conditions.

The design presented here is a standard approach that utilizes a highly-integrated control IC, the IRS2573D, to greatly simplify the design of the circuit. This solution also allows for scalability of design so that the same basic circuit can be used as a platform to realize a family of electronic ballasts for many lamp types and power levels. The new IRS2573D control IC contains the complete HID system-in-a-chip, including lamp control, lamp ignition, and all fault protection circuitry. This control IC makes the lighting solution very reliable and ideal for designers facing time-to-market pressures to introduce their products into the marketplace.

High intensity discharge lighting is a growing market with many applications. Outdoor lighting is especially attractive for high-intensity lamps, due to the long life-time and high-brightness these lamps deliver and the enormous energy saving benefits that electronic ballasts offer. The lamp requirements are critical and the ballast requirements are challenging, making the design of the electronic ballast a difficult task.